TP 5273E

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FINAL REPORT OF CONTRACT # 4778

TO : TRANSPORTATION DEVELOPMENT CENTRE, TRANSPORT CANADA

THE INCORPORATION OF KER-TRAIN CONTINUOUSLY VARIABLE TRANSMISSION

IN A MARATHON C-360 ELECTRIC VAN

KTS KER-TRAIN SYSTEMS LTD.

advanced transmission technology

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THE INCORPORATION OF KER-TRAIN [illegible]NUOUSLY VARIABLE TRANSMISSION IN A MARATHON C-360 ELECTRIC VAN

BY

J. Hugh Kerr

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for

Transportation Development Centre
Transport Canada

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17. Abstract

This report describes the installation of a Ker-Train binary logic, incrementally variable transmission in a Marathon C-360 electric van. The transmission had previously been designed and built by Ker-Train Systems Ltd. under a contract from the Department of Industry, Trade and Commerce.

The transmission was a fully automatic 9:1 to 1:1 64 step transmission controlled by a micro-processor.

After the transmission was installed, the vehicle was tested at the Transport Canada Motor Vehicle Test Centre at Blainville, Quebec, in order to compare its efficiency and performance to those of a similar van equipped with a Pinto manual transmission.

At the conclusion of the tests the transmission was disassembled and inspected. It showedno abnormal wear in any of its components.

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Voir aussi TP5258E, Ker-Train Variable Transmission - Track Testing Marathon Electric Vehicles Inc.	John H. Morgan

17. Résumé

Ce rapport décrit l'installation d'une transmission automatique dans une fourgonnette électrique Marathon C-360; fabriquée par Ker-Train, elle comprend 64 paliers de logique binaire entre 9:1 et 1:1, tous controllés par micro-processeur. Cette transmission avait été conçue et fabriquée par Ker-Train Systems Ltd., en vertu d'un contrat passé avec le département de l'Industrie et Commerce.

Après l'installation de la transmission, le véhicule a été testé au Centre d'essais pour véhicules automobiles à Blainville, Québec, afin de comparer l'efficacité et la performance de la transmission Ker-Train avec celles de la transmission manuelle d'une Pinto.

Les essais terminés, la transmission a été désassemblée et examinée. L'inspection n'a indiqué aucune usure anormale.

18. Mots-clés	19. Diffusion
Transmission automatique à 64 paliers. Fourgonnette électrique Marathon C-360. Essais.	Nombre limité de copies disponibles auprès de l'organisme parrain

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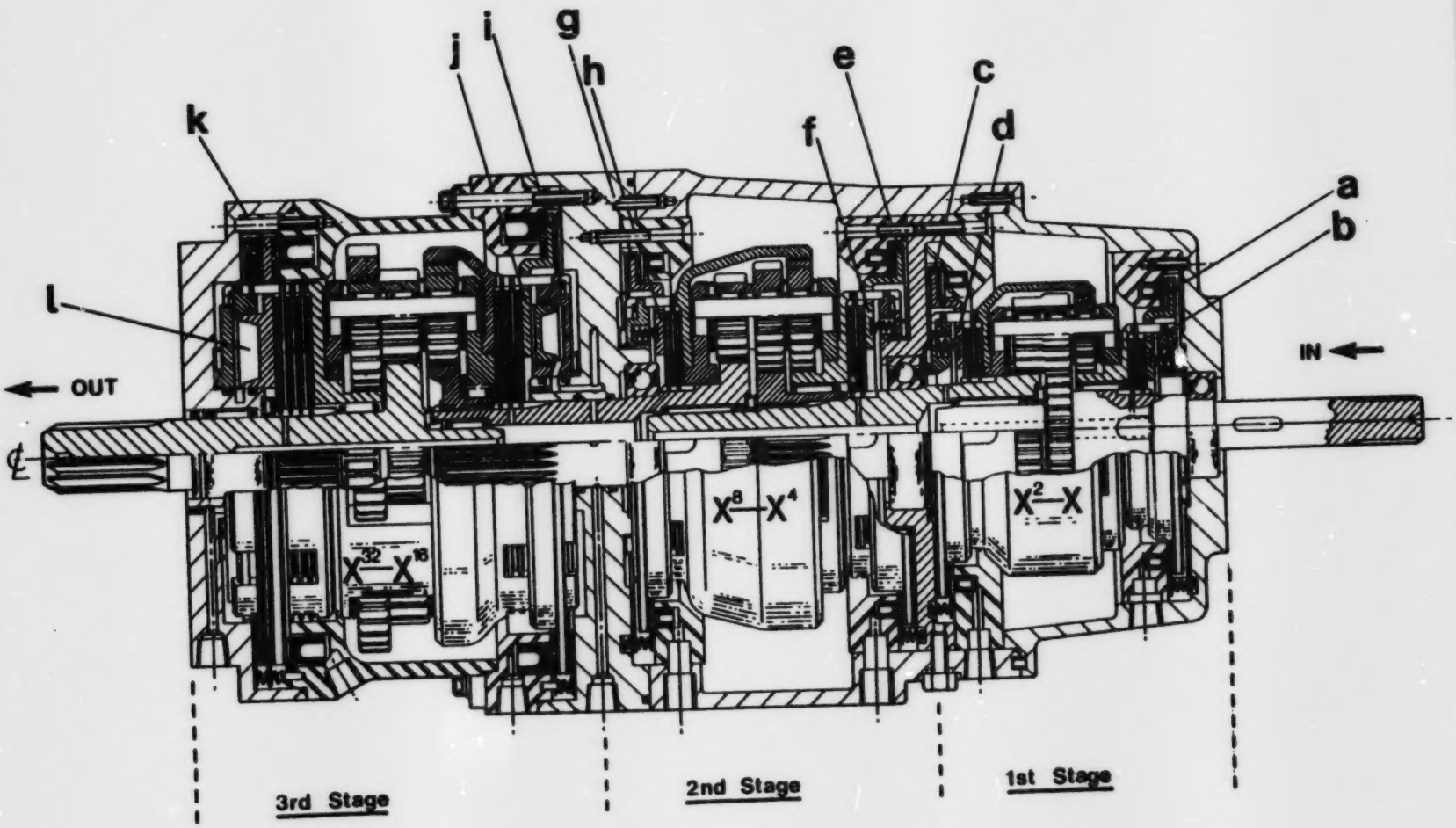
Binary Logic, Incrementally Variable Transmission.

(Patents Applied For.)

RANGE ——— 9:1 ——— 1:1

√SELECTABLE RATIOS — $(1{\cdot}0355)^{63}_{0}$

INCREMENTAL CHANGE — 3·55%



THE BINARY LOGIC INCREMENTALLY VARIABLE TRANSMISSION

FUNCTIONAL PARTS: Three quadriratio stages, consisting of primary reverted gear-train loops, intergrated into planetary gear-sets, and six binary clutch packs.

HOW IT WORKS: The induced reactive torques on the primary reverted gear-train loops of each quadriratio stage is split between the annulus and the sun pinion of their respective planetary gear-trains. These six interdependent reactive torques can now be coupled to either the transmission casing, or recirculated back to the reverted gear-train loops through the binary clutch packs, Selecting the binary clutch packs in sequential combinations decrements the 9:1 ratio reactive torque to zero, sixty-four ratio changes takes place, with output speed changing by even increments of 3.55% as each sequential ratio occurs.

COUPLING ACTION: The reactive torques on the lightly loaded clutch packs of the first and second stages are coupled to the transmission casing by hydraulic forces, and to their reverted gear-trains loops by spring forces that act on their interactive pressure plates. The more heavily loaded clutch packs of the third stage, are coupled to both by hydraulic forces.

TIME CONSTANTS: The time constants of the hydraulic-spring activated clutch packs are well under 0.3 second, with those of the hydraulic-only clutch packs extending to 0.7 second. 3-way solenoid valves are used to switch the clutch packs.

TRANSMISSION CONTROL: A microprocessor control module relates the position of both the accelerator and transmission selector lever to the power-torque-RPM efficiency array of the motor, then selects a transmission ratio from the solenoid valve switching array to obtain the desired motor operating speed to either maximize efficiency or provide maximum power from the motor. The control module utilizes both the acceleration and speed of the motor to deduce the magnitude and direction of the ratio change necessary to maintain motor speed within the desired speed regime. The Binary System Logic is shown in the table on page (2), where the ratio of the transmission is recorded as both a function of X the basic stage ratio(1 + incremental change), and the ratio of input to output.

CONTINUUM TORQUES: Continuum through the transmission is maintained during ratio changes, with the reactive torques on the clutch packs opposite to input rotation when in the driving mode, and in the same direction when in the coasting mode. They are, therefore, subject to both accelerating and decellerating forces during any normal operation profile.

Switching Order of the Binary System							
Clutch Number and Weight						Transmission Ratio	
1	2	3	4	5	6		
X^1	X^2	X^4	X^8	X^{16}	X^{32}	f(X)	Actual
1	1	1	1	1	1	X^{63}	9.0000
0	1	1	1	1	1	X^{62}	8.6915
1	0	1	1	1	1	X^{61}	8.3936
0	0	1	1	1	1	X^{60}	8.1059
1	1	0	1	1	1	X^{59}	7.8281
0	1	0	1	1	1	X^{58}	7.5598
1	0	0	1	1	1	X^{57}	7.3007
0	0	0	1	1	1	X^{56}	7.0504
1	1	1	0	1	1	X^{55}	6.8088
0	1	1	0	1	1	X^{54}	6.5754
1	0	1	0	1	1	X^{53}	6.3500
0	0	1	0	1	1	X^{52}	6.1324
1	1	0	0	1	1	X^{51}	5.9222
1	0	1	0	0	0	X^5	1.1905
0	0	1	0	0	0	X^4	1.1497
1	1	0	0	0	0	X^3	1.1103
0	1	0	0	0	0	X^2	1.0722
1	0	0	0	0	0	X^1	1.0355
0	0	0	0	0	0	X^0	1.0000

BACKGROUND

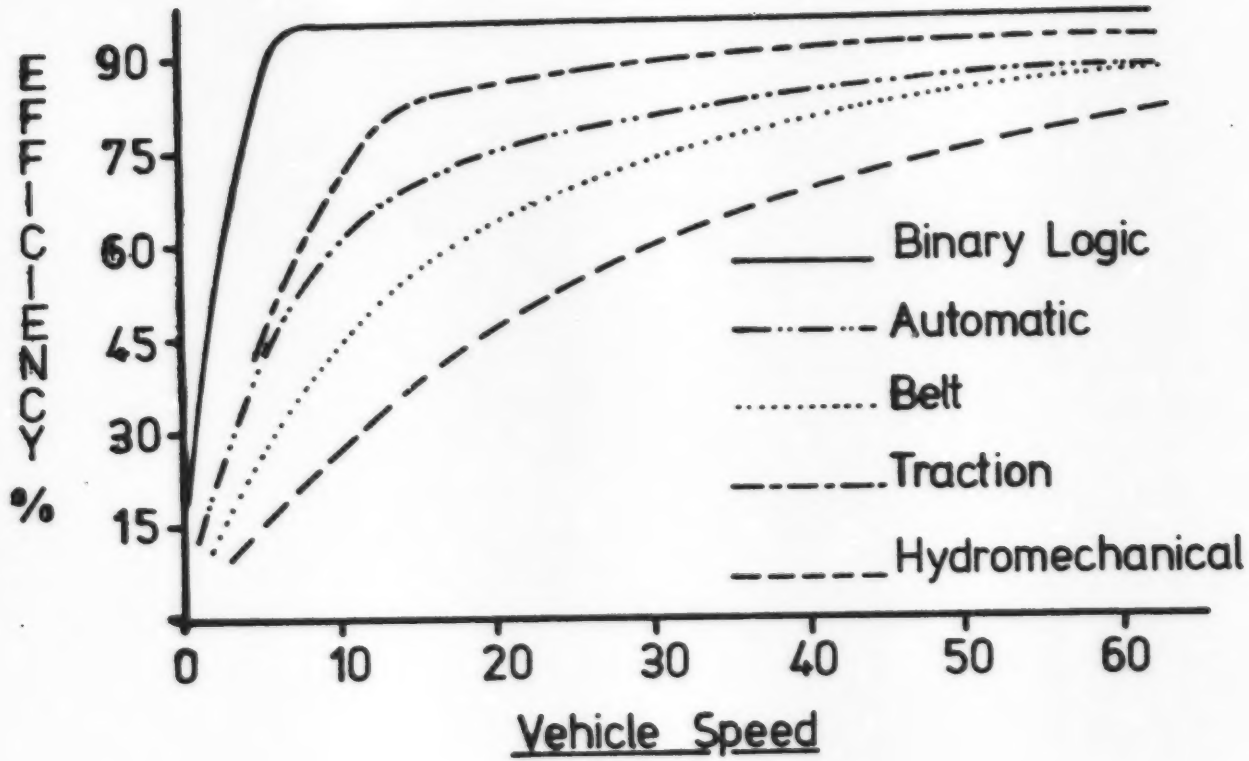
For a given power output, the maximum fuel efficiency of an internal combustion engine is achieved with a particular combination of engine output torque and speed. An unrestricted combination of engine torque and speed is only possible if a continuously variable transmission (CVT) is incorporated in the drivetrain.

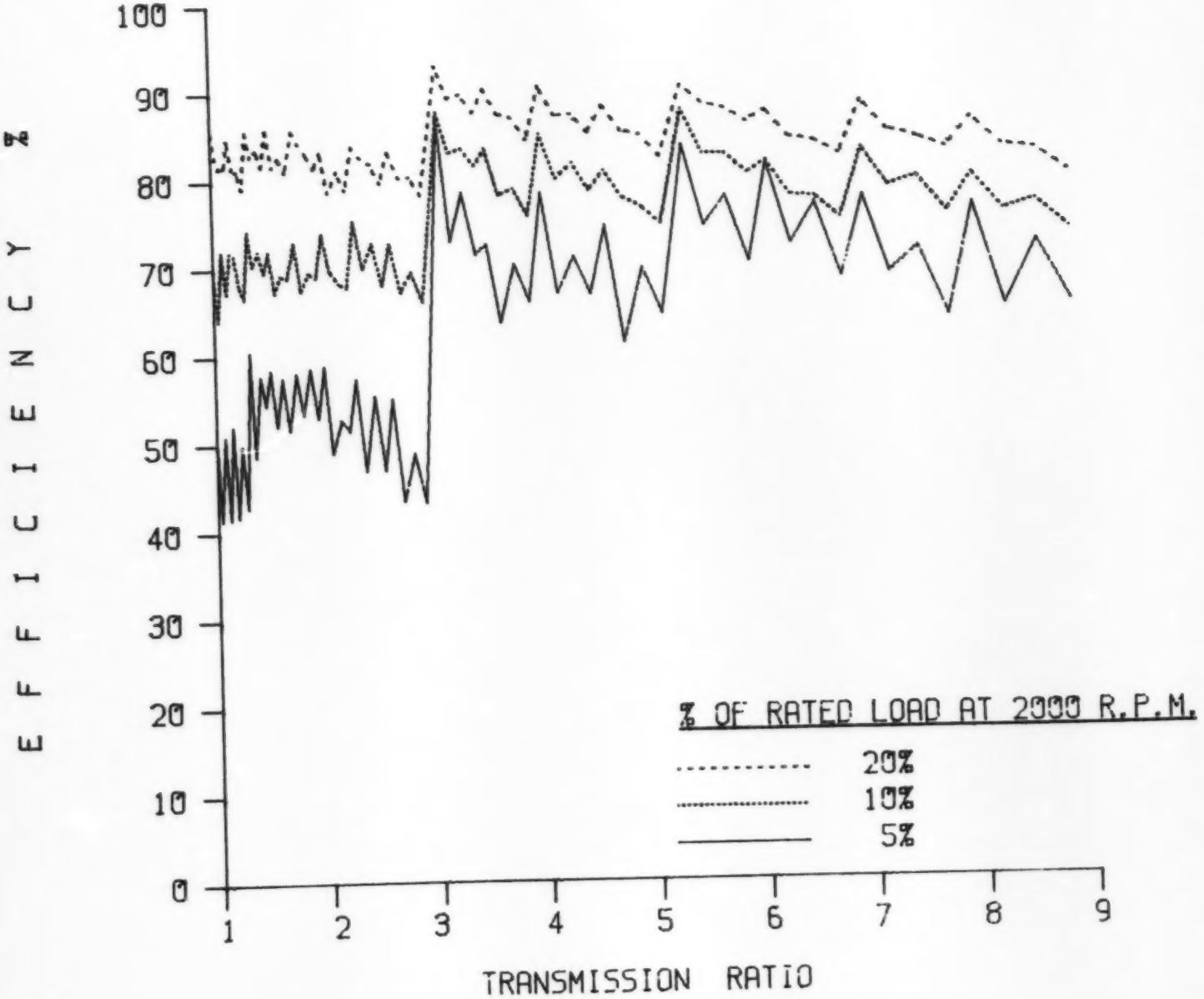
Eighty years have elapsed since the first CVT appeared in the automobile, and ever since it has remained the elusive dream of the drivetrain designer. Numerous forms of CVTs have appeared over the years, but, as yet none have met the high efficiency, cost, and reliability demanded from the automotive industry.

Although the ratio in a Binary Logic Incrementally Variable Transmission (BLIncVT) varies incrementally, the changes are small and engine efficiency is no more impeded than with a CVT installation. The viability of a BLIncVT should be compared with the present state-of-the-art traction, hydrostatic, and vee-belt drives within the context of a CVT, and in structure to the more familar hydrodynamic transmissions, but, without the torque converter. Further, all gear elements remain in continuum irrespective of the ratio with no rotation occuring in many gear-sets during the ratio changes, and at ratio unity the entire transmission becomes a solid coupling. The resulting overall efficiencies far exceed most manual transmissions. The graph page (4) compares the full load operating efficiency of the favored CVTs, the hydromatic, and the BLIncVT.

Any analysis of the "Binary Logic Transmission Concept" shows clearly the simple layout, simple parts structure, compactness, light weight, and fundamental elegance.

EFFICIENCY COMPARISON OF TRANSMISSION DRIVES




EFFICIENCY %
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
TRANSMISSION RATIO
% OF RATED LOAD AT 2000 R.P.M.
20%
10%
5%

(5)

REVIEW OF INSTALLATION AND TESTING PROBLEMS OF

THE BINARY LOGIC INCREMEANTALY VARIABLE TRANSMISSION

IN THE MARATHON C-360 ELECTRIC VAN

(1) COMPUTER HARDWARE/SOFTWARE MODIFICATIONS

(a) The computer software as originally prepared contained a completely intergrated motor regenerative capability that required only a brake position transducer and regenerative hardware in the vehicle electric system. This was included in the original software package as requested by both Marathon and Transport Canada. Since the vehicle provided for the transmission installation did not have any regenerative hardware, an extensive rewrite of the software was necessary to insure no inadvertant downshifting of the transmission would occur.

(b) Initial tests indicated that the transmission input speed Hall-field-effect-sensors was giving random readings of speed to the computer. This was originally thought to be radio interference, but turned out that the magnetic field was distorted as the magnet passed over the steel screws which held the sensors to their mounts. This was solved after much trial and error, and resolved by substituting the steel screws with brass ones.

(c) Radio interference from some unknown source, interferred with the computer on many occasions and force a premature shifting of the transmission. Although they could not be isolated, added shielding and readjustment of the air gap in the motor rpm Hall-field-effect pick-up transducer appeared to have eliminated this problem.

(d) Clutch closure time constants for all six binary clutches were initially set at .5 seconds in the software of the transmission control computer. Full range road tests were then conducted to ascertain the qualitative irregularly in the shift pattern of the transmission that would be due to these optomistic settings. The resulting irregularities firmly established that some consideration must be given to the real time constants of the binary clutches for both their step-up and step-down modes. Accordingly, the software was modified to accept an arbitrary listing of time constants for each of the two modes for all six clutches. Thus, through trial and error, different time constant settings were set in the computer clutch pack array until a satisfactory combination, that more closely approximated the true time constants of the transmission, produced a smooth stepping action over the entire 9:1 to 1:1 range. This proceedure was necessary as the

actual time constants of the clutch packs were unknown since they could not be measured with the limited bench test facilities available in the transmission development program.

(f) During the road tests on the morning that the vehicle was to be delivered to Montreal, two of the darlington pairs that control the hydraulic solenoid valves in the high current circuitry of the computer burnt out. Fortunatly, replacements from a second computer were available and no delay in delivery resulted. However, re-examination of the high current circuitry suggests that this could be a reoccuring fault, and consequently the circuit has been redesigned with larger capacity units and will be modified when it is convenient.

(g) After the vehicle had been at Blainsville for several months all of the darlington pairs burnt out. Fortunatly it was just a matter of substituting the redesigned circuit in the computer to make it operational again.

(h) A second trip to Blainsville was made several months later to repair a reported fault in the computer. When the party arived they were told that the fault had been found, someone foregot to recharge the vehicle batteries.

(2) LUBRICATION AND CONTROL OIL

(a) ASCO, electrically activated hydraulic solenoid valves were selected to operate the transmission clutches. Bench testing of these valves showed some promise. In the vehicle installation they showed total unreliability.

During our discussions with the Orshansky people it was learned that they developed a valve for use in their hydrodynamic CVT transmission that was funded by EPA(US) to a sum of approximately thirty million dollars. The development was necessary as there was no suitable valve on the market.

A new hydraulic block assembly was manufactured to accomodate six Orshansky HSV-3000 electrically activated hydraulic valves. Their performance was very adequate!

(b) During driving trials of the vehicle a transmission lockup occured. Damage to the third stage input shaft and end plate require that they be reworked. Investigation showed that a piece of rubber from one of the hydrualic hoses had worked its way lose and blocked the main lube passage to the transmission.

The necessary rework was done and a seperate inline filter was placed on the lube line. No other lubrication problems were incountered

(c) After driving the vehicle for some 120 miles over a two weeks period without any apparent problems, the seal on the trans-

imission oil pump developed a leak. The fix required removing the transmission and replacement of the seal.

(d) A further delay was caused by a faulty oil seal in the electric oil pump, with a replacement seal taking some ten days of valuable time.

(e) After the vehicle had been at Blainsville for a few weeks an oil leak was reported in the front of the transmission. An inspection visit to Blainsville found the problem to be a hydraulic fitting that had vibrated loose. The fitting was replaced and the party returned to Kingston.

(3) TRANSMISSION

(a) during the dynamometer testing of the second transmission at NRC the lubracating oil become contaminated and the unit was removed for examination. Examination showed that the countershafts had picked up aluminum from the planetary cages. The main reason for this was that proper material for the cages was unavailable at the time of manufactering and the substitute material was simply not good enough. Steel thrust washers were fitted to the cages of both transmissions, and they solved the problem of cage rub.

(b) during a road test a high pitch noise developed in the transmission area. After removal and tear down without finding any apparent cause in the transmission, the noise was finally found to be coming from a loose bracket on the electric motor.

FINAL INSPECTION OF THE TRANSMISSION

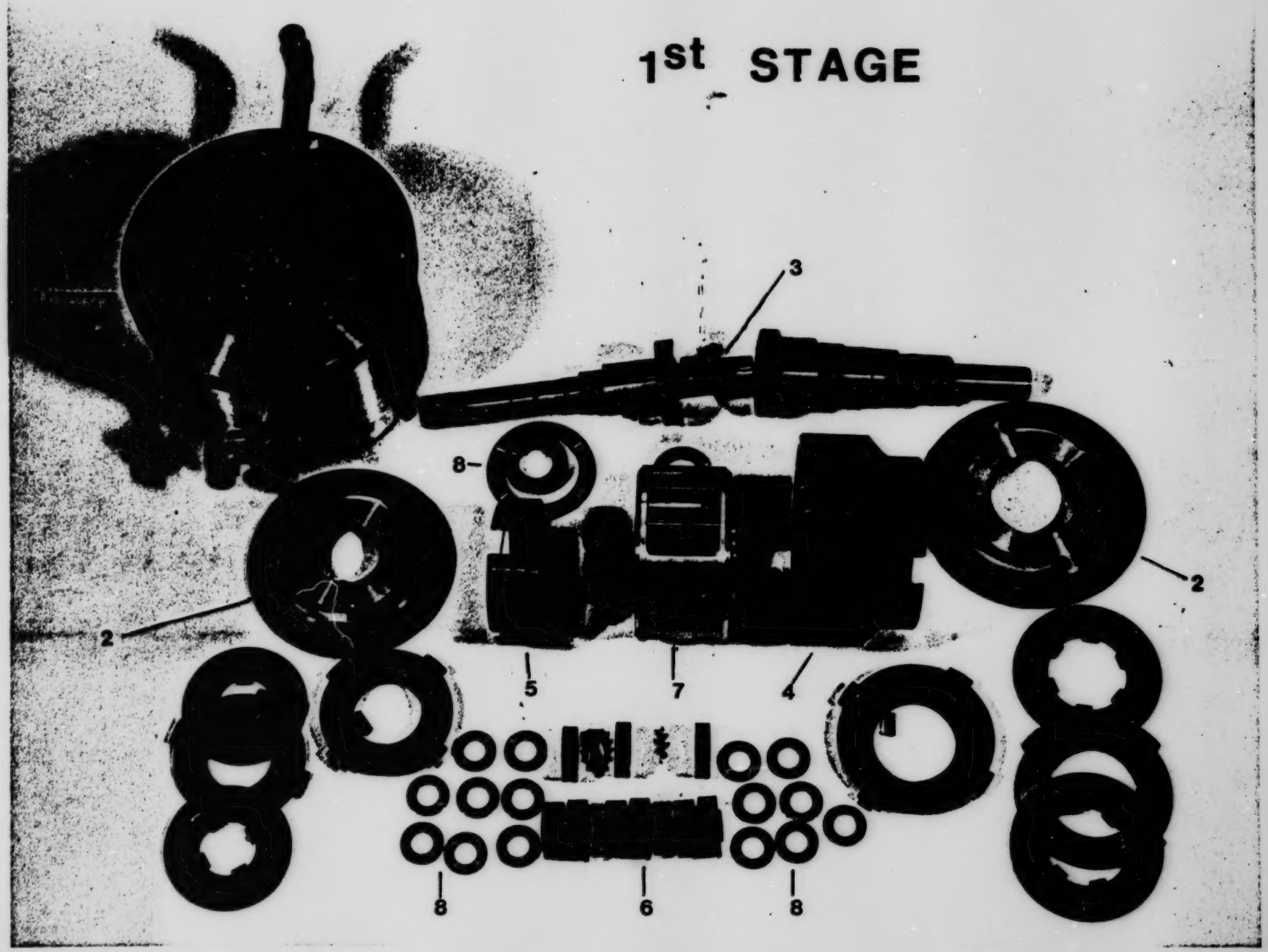
After the completion of the road tests at Blainsville we received the transmission from Marathon for our final inspection. The unit was dismantelled and the components of each stage were inspected for wear. No component showed any unusual signs of wear. The clutch plates and bearings are like new, with the gears just starting to show signs of polishing up.

The NRC transmission was similarly inspected and found to have only a slight additional wear. This was expected as the NRC transmission had completed some 500 hours of testing.

Pages 10,11, and 12 are photographs taken after the final insepection of the transmission fitted in the Marathon Van showing all of the dismantelled componets of the three stages.

PHOTOGRAPH LEGEND	
ITEM #	DESCRIPTION
1	CASING WITH END PLATE
2	BINARY CLUTCH ASSEMBLES
3	INPUT/OUTPUT SHAFTS
4	ANNULAS GEAR
5	SUN GEAR
6	CLUSTER GEARS
7	CAGE
8	BEARINGS

1st STAGE



2nd STAGE
1
2
3
4
5
6
7
8

3rd STAGE
1
2
2
3
4
5
6
7
8

SUMMARY OF PROJECT COSTS

CONTRACT No. 4778

COMPANY NAME: KER-TRAIN SYSTEMS LTD.
BOX 40, RR1
KINGSTON, ONTARIO
K7L 4V1

PROJECT NATURE: INSTALLATION OF A KER-TRAIN INCREMENTALLY TRANSMISSION (IVT) IN A MARATHON C-360 ELECTRIC VAN.

ESTIMATED TOTAL COST: $ 15,000.00

CONTRIBUTION BY CROWN TO DATE : 13,500.00

SUMMARY OF ACTUAL COSTS INCURRED

DIRECT LABOUR	15,725.00
CONSULTING SERVICES	2,942.92
GENERAL TRAVEL EXPENSES	1,100.83
MATERIAL/MACHINING/MISC.	11,364.81

TOTAL COST INCCURED BY KER-TRAIN SYSTEMS TO DATE : $31,133.56

CROWN"S SHARE OF TOTAL COST : $15,000.00 (100%)

DEFICIT : $16,133.56